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THE HEART[1] MOUNTAIN OVERTHRUST, WYOMING[2]

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SUMMARY OF RESULTS

The recognition in 1919 of blocks of Madison limestone (Mississippian) overlying beds of the Bridger epoch (middle Eocene) in the McCullock Peak region, 12 miles east of Cody, Wyoming, shows that the overthrust fault recognized by Dake (2) in 1916 is much more extensive than first suspected. Dake mapped the fault in a belt 30 miles long, within which the extent of overthrust was estimated at 16 miles. He also noted the existence of thrust faults along the east front of Beartooth plateau, where pre-Cambrian rocks overlie "Red Beds" (Chugwater formation) but did not assume continuity with the Heart Mountain overthrust. The residuals on McCullock Peak show that the extent of overthrust is at least 28 miles and indicate that the fault should be traceable over the entire eastern edge of Absaroka Range, perhaps for 125 or 150 miles.

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[1] This spelling approved by United States Geographic Board, 1909.

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On the basis of exposures in the mountain region, Dake was able to conclude that the overthrust took place after the deposition of his Fort Union (?) (early Eocene) beds and before the outbursts of the "early basic breccias (Neocene or upper Miocene)" described by Hague. The McCullock Peak outliers show that the overthrust is probably post-Bridger (middle Eocene).

It may be recalled that Richards and Mansfield (15*a*) concluded that the Bannock overthrust in southeastern Idaho was developed before the deposition of Wasatch beds (lower Eocene). Similarly Veatch (16*a*) concluded that the Absaroka overthrust in southwestern Wyoming was developed after the deposition of the Almy and Fowkes beds (lower Wasatch) and before the deposition of the Knight formation (upper Wasatch, lower Eocene). On the north, Willis (17*a*) concluded from physiographic rather than stratigraphic evidence that the Lewis overthrust was developed in mid-Tertiary time, and was completed before the Miocene epoch. Although further work will undoubtedly determine more closely the periods at which these four overthrusts were developed, it appears highly probable at present that, although they lie in a belt scarcely 500 miles long, they did not take place simultaneously. The Lewis overthrust may have been nearly simultaneous with the Heart Mountain overthrust, however.

A brief reconnaissance by the writer in the region west of Cody studied by Dake confirmed his conclusion that the overthrust beds were deeply eroded before the outbursts of the early basic breccias of the Yellowstone Park region (upper Miocene). Evidence obtained by the writer previously between Owl Creek and Wood River, however, indicates that there was conformable deposition of the Bighorn Basin Wasatch and the overlying tuffs and breccias of that region, which are here tentatively correlated with the "early acid breccias" of the Absaroka Range (lower Eocene). It is concluded that the overthrust took place after the deposition of the "early acid breccias" and before the outbursts of "early basic breccias" and is, therefore, middle Eocene or early Oligocene in age.

INTRODUCTION

It is the principal purpose of the present article to set forth observations in the McCullock Peak region that bear upon the extent and age of the Heart Mountain overthrust. It will be apparent, however, that such a profound structural feature must consistently fit into the complex Tertiary history of sedimentation and orogenic movements in the region, so that it seems advisable to set forth here some of the problems of the region and some of the data that must be adjusted to a correct and comprehensive interpretation of that history. As the writer has devoted parts of the field seasons of 1911, 1912, 1913, 1916, and 1919 to detailed investigations in three fifteen-minute quadrangles that lie between Cody and Thermopolis, southeast of the region in which the overthrust has been observed, some conclusions must be stated without giving much of the evidence on which they are based.

SURFACE FEATURES

The Bighorn Basin (4, 5, 14) is an elliptical area of low relief with few conspicuous hills or mountains, surrounded on the east, south, and west by mountain ranges. For purposes of physiographic, stratigraphic, and structural description, it may be considered as made up of two parts, a central part 75 miles long by 45 miles wide, which largely coincides with the area of Wasatch and younger beds, and a border belt 10 to 20 miles wide, which lies between the central part and the mountain ranges that surround the basin. These ranges include the Bighorn Mountains on the east, the Bridger and Owl Creek ranges on the south, and the Absaroka Range and Bear-tooth Plateau on the west. Figure 1 shows some of the features and geology of an area in the northwestern part of Bighorn Basin, which extend from the eastern edge of the Absaroka Range, across the border belt to the center of the basin. Figure 2 shows two sections across this region.

The central part of the basin contains large areas of flat uplands that lie several hundred feet above the nearby valleys. There are also extensive areas of bad lands where erosion has cut back into the uplands. The central part contains three conspicuous elevated areas that rise above the uplands, and that range from 1,200 to

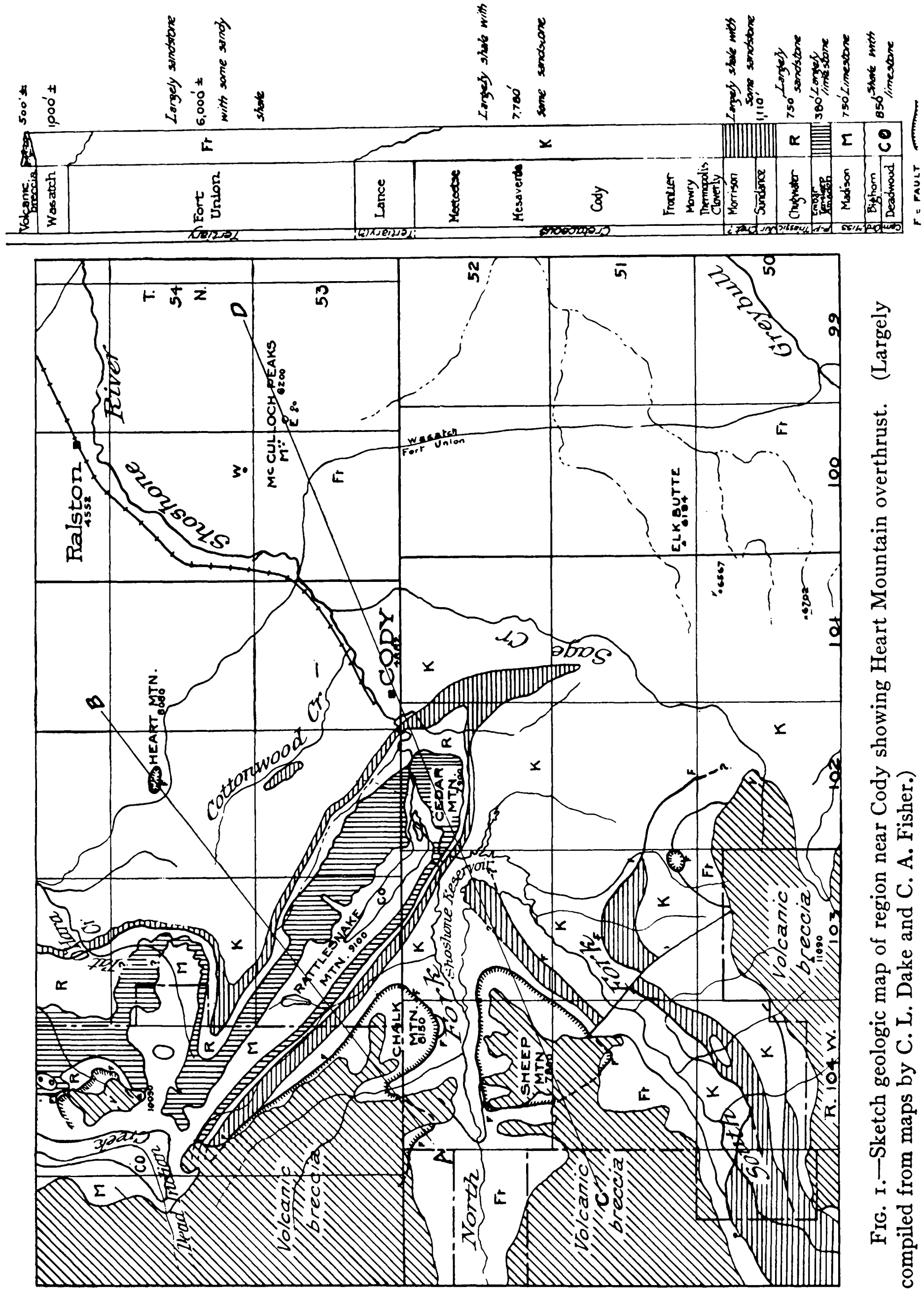

FIG. 1.—Sketch geologic map of region near Cody showing Heart Mountain overthrust. (Largely compiled from maps by C. L. Dake and C. A. Fisher.)

1,500 feet above the nearby streams; Squaw Buttes (6,200 feet), Tatman Mountain (5,800 feet), and McCullock Peaks,[1] three in number and approximately equal in elevation (6,200 feet). Heart Mountain (8,080 feet) is a conspicuous peak that lies west of the central part of the basin, where it merges with the border belt.

The border belt is largely made up of long stretches of flat upland terraces that rise gently toward the mountains. Most of the streams have cut broad terraced valleys below the uplands. The rocks exposed in this belt range from the Chugwater formation ("Red Beds") to the Fort Union formation (lower Eocene), and attain a maximum thickness of about 15,000 feet on the west side of the basin. The successive formations are brought to the surface in a series of pronounced folds whose axes are roughly parallel to a median trough in the central part of the basin. Dips that range from 15° to 60° are common along the flanks of the folds (14*a*).

In a broad way, the mountains that limit the basin on the east, southeast, and south, the Bighorn (4), Bridger (4), and Owl Creek (3) ranges respectively, are rather simple smooth ridges that coincide with extensive anticlines. The mountains west of the basin (10) are high and rugged and present an imposing front toward the basin. They coincide roughly with an area of volcanic tuffs, breccias, and flows that are a part of the extensive field of volcanic rocks which covers northwestern Wyoming and eastern Idaho.

STRATIGRAPHY

It will be sufficient at this place to state briefly the general features of the Paleozoic and Mesozoic sections and such details of the Fort Union, Wasatch, and younger rocks as bear upon the age of the overthrust and the physical conditions surrounding the process. The commonest underlying pre-Cambrian rock in this region is a rather homogeneous red granite which is locally cut by diabase dikes.

The Paleozoic and Mesozoic sections are separable into three groups on the basis of lithology and degree of induration, which measure their strength. The first and strongest group includes the Paleozoic limestones and associated sandstones and quartzites,

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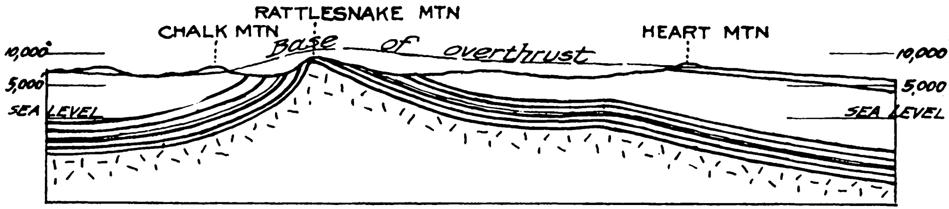
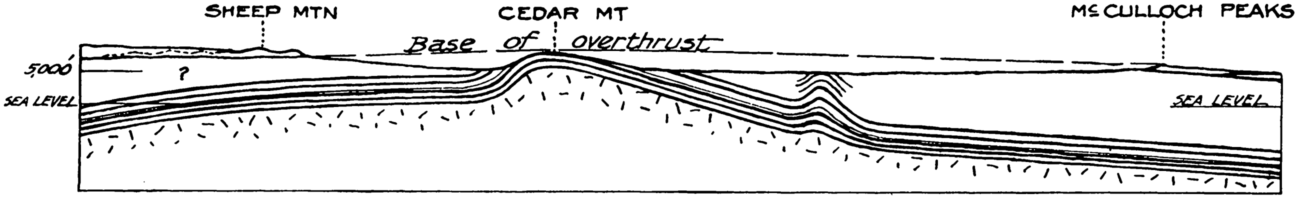
[1] Commonly referred to as McCullock Peak.



SECTION ALONG LINE A-B



SECTION ALONG LINE C-D

FIG. 2.—Cross-sections of the Heart Mountain overthrust

that include the beds from the Bighorn limestone (Ordovician) to the Embar group (Permian and Pennsylvanian), the sum of whose average thicknesses in this region is about 1,280 feet. Most of this thickness is beds of dense homogeneous gray limestone that range from 5 to 50 feet thick. This group is to be regarded as the most competent unit in the entire section.

The second group includes several distinct sandstone formations, such as the Chugwater (Triassic) about 750 feet thick, and Mesaverde formation (Upper Cretaceous), which is largely sandstone and about 1,200 feet thick. Both of these formations include some shale. As the Chugwater formation overlies the Paleozoic limestones and sandstones, it would tend to increase the strength of those beds.

The third and weakest group includes the remaining formations. The Deadwood formation (Cambrian) made up of shale and sandstone is 700 feet thick. The Mesozoic and Tertiary formations (12, 14) that are made up of thin soft sandstones, locally conglomerate, sandy shale, and shale include the Sundance, Morrison, Cloverly, Thermopolis, Mowry, Frontier, Cody, Meeteetse, Lance, Fort Union, and Wasatch formations, 13,600± feet thick.

It will be noted that the most competent unit is that which includes beds that range from the Bighorn limestone (Ordovician) to the Chugwater sandstones (Triassic) about 2,030 feet thick. If this section be compared with others of regions in which large overthrust faults have occurred, the thinness of the competent part of the section is impressive.

The characteristics and structural relations of those beds only that may bear upon the period of overthrusting will be presented here. The recognition of the Fort Union formation on the west side of Bighorn Basin is based upon numerous collections of leaves that have been studied and identified by F. H. Knowlton. The base is considered to be a conglomeratic sandstone, which is locally unconformable on underlying beds that range from the middle part of the Meeteetse formation (roughly equivalent to the Judith River formation of the Montana group) to the top of the Lance formation ("Ceratops beds"). This unconformity has only been recognized in one locality east of Oregon Basin for a distance of

15 miles where a maximum of about 2,000 feet of beds were here eroded before the deposition of the lowest Fort Union beds. The contact of these beds with the underlying Lance formation in a belt 50 miles southeast, however, yields no evidence of unconformity. The unconformity indicates local warping and erosion of the Lance and older beds before the deposition of the lowest Fort Union sandstone.

The top of the Fort Union formation in this region is a persistent unconformity at the base of beds that yield a large mammalian fauna until recently called Wasatch but now known to be characteristic of the Wind River formation (8, 9).

The unconformity is readily recognizable at every locality where dip cross-sections of the beds may be seen, but in strike sections it can only be detected by close study of the lithological features.

Within these limits, the Fort Union formation attains a maximum thickness of more than 5,250 feet and is made up of many beds of pale yellowish buff and white sandstone alternating with gray, olive, and red shale. The sandstones of the lower 200 feet commonly contain lenses of pebbles of many rock types. Black and gray chert predominate but red and gray quartzite, pale pink porphyry, gray sandstone, and silicified wood are common. Pink granite and coal pebbles are sparingly present but limestone has never been found. The chert pebbles have yielded an interesting collection of invertebrate fossils which are characteristic of the Madison and Embar formations. At least three coal beds occur in the lower 600 feet of the formation on the west side of the basin. Thus far, in this region, the formation has yielded a single vertebrate bone, but no invertebrate fossils. No bentonite or volcanic ash have been recognized in it.

There are good reasons for believing that the beds here considered as the Fort Union formation are part of an extensive sheet of sediments spread over a large area of Wyoming and Montana, at least as far west as the Rocky Mountains, and eastward into the Dakotas. They probably covered the site of the present Bighorn, Bridger, and Owl Creek Ranges. These beds are so involved in the folds of the border belt of the basin that it is concluded that these as well as the long anticlines which coincide with the Bighorn, Bridger, and Owl Creek ranges, were developed after the beds were laid down. The folds are broken by many normal faults of small displacement, none of which appear to pass into the overlying Wasatch beds.

The term Bighorn Basin Wasatch has long been considered to include the sandstones and alternating olive and red clays of the central part of the Bighorn Basin, where they attain a maximum thickness of about 2,500 feet. These beds include light brown and white sandstones, gritty arkose and pale olive, gray, and red clays. The sandstones locally contain pebble zones of re-worked Fort Union materials, with the addition of limestone and granite which are absent or uncommon in those beds. Although bentonite has been reported east of Meeteetse (5), no unaltered volcanic tuff has yet been recognized. The beds are nearly horizontal over large areas in the center of the basin, and although the range along the border is commonly 3° to 10°, dips as high as 20° are known (9).

The beds of the central part yield a large vertebrate fauna which has been studied from time to time. Only a few invertebrate fossils are known in the beds (5). The recent careful faunal studies of Granger and Sinclair show that the Bighorn Basin Wasatch contains beds that range from "Paleocene" (their Clarks Fork beds) to uppermost lower Eocene (their Lysite or Upper Wind River beds) (7, 8, 9).

The early work of Eldridge (6) as well as the later work of Fisher (5) showed the presence of a persistent nearly horizontal layer, composed of sandstone and gray and red shale underlying volcanic tuffs in the region between Meeteetse Creek and Owl Creek in the southwest part of Bighorn Basin, and they were considered to be Wasatch. These beds outcrop along the south edge of the Meeteetse quadrangle and the west edge of the Grass Creek quadrangle which have been studied by the writer. In addition to the alternating olive and red shale and sandstones with local chert and quartzite pebble lenses, which are characteristic of the Wasatch deposits of the central part of the basin, there are thin beds of dark carbonaceous shale, carbonized plant remains, and thin lenses of coal. The thickness of the layer ranges from 125 to 250 feet. It lies on a surface of low relief cut across the folded Cretaceous rocks, and as the base rises from an elevation of 6,000 feet near Owl Creek to 7,200 feet near Wood River, a distance of 21 miles, it appears to have been slightly warped since deposition. North of Cottonwood Creek a narrow east-west strip has been down-faulted about 360 feet.

Throughout this region, these beds are apparently conformably overlain by paper-thin carbonaceous shales that weather white, and these, in turn, by pale greenish volcanic ash and light brown tuff, locally indurated. About 100 feet above the typical Wasatch sediments, the well-stratified fine material is succeeded by coarser, cross-bedded light brown tuff and still higher by heterogeneous fine and coarse brown andesitic breccia that makes up the masses 3,000 to 4,000 feet thick in the region east of the Washakie Needles. Except for the reference to lava flows, which are not known between Wood River and Owl Creek, the following statement by Blackwelder might be considered an accurate description of conditions in the southwest part of Bighorn Basin (1*a*):

> At the northwest end of the Wind River Range, where it articulates with the mountains of Yellowstone Park, thick beds of volcanic ash and agglomerate with interbedded glassy lava flows rest upon the pre-Tertiary folded rocks, but are themselves younger than the Wind River Eocene. Traced eastward to Horse Creek, the Washakee Needles, and the valley of Owl Creek, this thick volcanic series is found to rest conformably upon the striped clays of the Wind River formation, with which they intergrade through gray, plant-bearing shales and greenish volcanic sandstones containing petrified logs. A closer examination of the volcanic beds shows that some of them are massive agglomerates, devoid of stratification, whereas other beds are distinctly stratified, cross-bedded, and occasionally interrupted by lenticular sheets of coarse gravel, suggestive of stream channels. The conditions indicated are those which would be found upon low gradient river plains adjacent to active volcanoes.

The stratified tuffs have yielded several collections of leaves, one collected by Mr. N. H. Darton (3*a*) on the Middle Fork of Owl Creek and one by the writer south of Sunshine. Both are considered characteristic Fort Union material by F. H. Knowlton. No vertebrate or invertebrate fossils have yet been found in the supposed Wasatch beds, or the overlying tuffs or breccias.

The relations between the beds described above, which may be referred to as the border Wasatch, to the Bighorn Basin Wasatch might be uncertain if it were not for the existence of remnants on hilltops in several parts of the border belt. These remnants have the same lithologic features as the border Wasatch and some of the beds rather high in the section of the Bighorn Basin Wasatch in the Tatman Mountain section. A longitudinal section through three of these remnants from a point south of Sunshine northeast toward the basin shows that they are part of a river channel which extended from the foothills of the border belt out into the basin with a gradient of 25 to 70 feet to the mile. It is the writer's opinion that the border Wasatch was laid down at the same time as some of the beds that make up the Lost Cabin or Tatman Mountain beds (upper Wind River) of Sinclair and Granger in the central part of Bighorn Basin. The particular significance of the border Wasatch beds is that they indicate that there has been little if any local folding of the Cretaceous and Fort Union beds of the border belt since upper Wind River beds were laid down. The border Wasatch has, however, been broadly warped and locally faulted.

Only tentative conclusions concerning the age and correlation of the stratified tuffs and breccias that overlie the border Wasatch can be made at this time. In considering this problem the writer has had the benefit of informal discussion with Dr. J. P. Iddings, who examined a large part of the area of the Yellowstone Park (11) and that covered by the Absaroka folio (10).

It may be recalled that along the headwaters of Lamar River (Cache Creek) and Clark's Fork (Republic Creek) several varieties of light colored andesitic tuffs and breccias, locally distinctly stratified, underlie the darker, basaltic breccias that cover a large area east of Yellowstone River and Lake, and north of the latitude of Greybull River (10). Although locally, the lower group ("early acid breccias") appears to merge upward with the upper group ("early basic breccias"), elsewhere there is evidence of considerable erosion of the lower group before the deposition of the upper group. The lower group yielded a large flora, considered by F. H. Knowlton to be Fort Union (lower Eocene), whereas the flora of the upper group, likewise large, is considered to be upper Miocene. From the evidence of this region, one must conclude either (1) that the period of erosion intervening between the deposition of the two groups of breccias was brief and therefore that the floras are misleading, or (2) that the intervening period of erosion was rather long, probably persisting from upper Eocene time through Oligocene and lower Miocene time, as the floras indicate. Dr. Iddings agrees with the writer that the latter conclusion is more acceptable at present. He further considers that the lithology and flora of the tuffs and breccias between Owl Creek and Wind River warrant the tentative correlation of them with the "early acid breccias" of the Yellowstone Park region. It is apparent, however, that considerable additional work must be done before the relations of the volcanic rocks of the southern Absaroka Range are proved.

MCCULLOCK PEAK EXPOSURES

The foregoing statement of the lithologic features and structure of the Fort Union and Wasatch beds of the Basin permit a more careful consideration of the exposures near McCullock Peak and the relations of the overthrust recognized by Dake west of Cody.

In previous descriptions of this region, the name "McCullock Peak" has been applied to the central part of a high rugged area, about 4 miles long by 2 miles wide, 12 miles east of Cody. (Figure 3 shows a view of the McCullock Peak area from the west.) In the following description of the region, three culminating summits will be referred to as West Peak, Middle Peak, and East Peak, respectively. Although extensive gravel-covered terraces extend south from the peaks for several miles, the entire elevated region is completely surrounded by typical bad lands, and the rock exposures are uncommonly good.

West Peak lies about two miles northwest of Middle Peak and is connected with it by a sinuous rugged ridge. It is the culminating point of a rugged bad lands area carved from nearly horizontal Wasatch beds. It is almost devoid of vegetation and the terraced ridges of alternating gray, olive, and red shale and sandstone present an impressive picture from the east, north, and west. It was not visited by the writer, but several attempts to ascend it by horseback from the west are known to have failed.

Middle Peak may be readily ascended from the south along a gravel-covered terrace of gentle gradient. The summit is smooth and the adjacent slopes, except on the north and west, are covered with grass and dwarfed sage-brush. If viewed from the west, the summit appears to be a part of the terrace which extends southward, but if critically viewed from the south it appears to be a smooth hill that projects about 200 feet above the extension of the terrace. In other words, it appears to be the residual mass of a more imposing hill that was in existence while the plain of which the terrace is a remnant was being formed. Good rock outcrops are confined to the west, north, and northeast slopes of Middle Peak, where nearly horizontal sandstones, locally arkosic, alternate with pale olive and red clays. The material is similar to that which makes up the bulk of the Bighorn Basin Wasatch. The

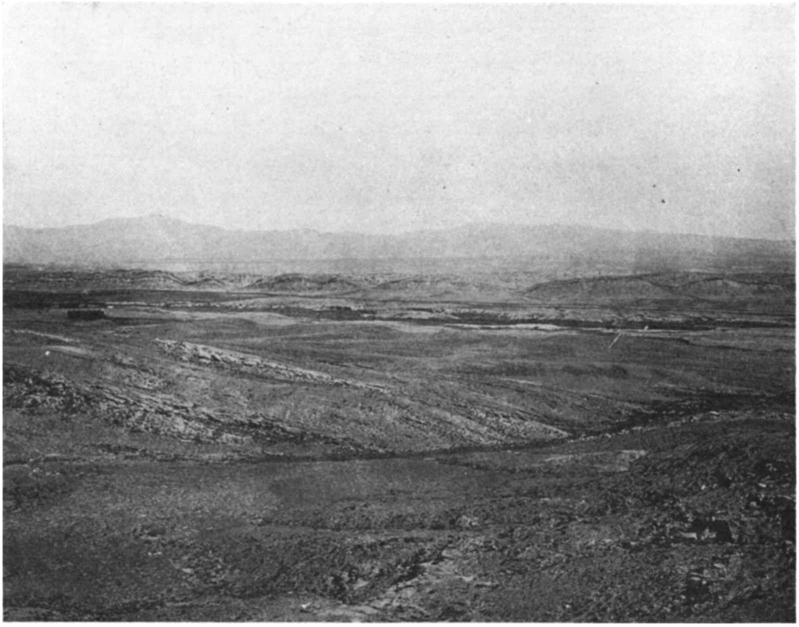


FIG. 3.—The McCullock Peak region viewed from the southwest, near Cody, Wyoming. West Peak lies on the left; East Peak rises above the terrace on the right; Middle Peak is the low cone just left of East Peak.

fossils which are described below were collected from a 50-foot zone of gray, olive, and red clays that are well exposed along a narrow ridge 1,000 feet northeast and 150 feet stratigraphically below the summit.

The fossils were first referred to J. W. Gidley of the United States National Museum, but, as field parties from the American Museum of Natural History have closely studied and made numerous collections from these beds, it seemed advisable to refer the fossils to them also. The statements of Mr. Gidley (*a*) and of Mr. Walter Granger (*b*) are attached:

a) A preliminary report was furnished to Dr. Stanton on November 25 (unofficially). It was as follows:

"No. 1. The largest tooth is a right upper third or last molar of *Helaletes;* of. *nanus* Marsh. Not known outside the Bridger horizon.

"No. 2. The next smaller tooth is a last left upper molar of *Eohippus* sp.

"No. 3. The fragment of jaw containing two teeth I have not been able to definitely determine."

In addition, I may now say that a further study of the small jaw fragment seems to warrant referring it to *Hemiscodon pucillus* Marsh, with which it agrees almost exactly in size. This determination, however, cannot be made positive without comparing it with the type, which is probably in the Yale Museum collection. This is a Bridger species.

It would thus seem that the three specimens represent a Bridger fauna, although the Eohippus tooth suggests Wasatch rather than Bridger affinities.

b) I have examined the three specimens of mammal teeth from Eocene beds near the top of McCullock Peak, Wyoming, and submit the following determinations:

(1) *Helaletes*, a last upper molar of the right side.

(2) *Eohippus*, a last upper molar of the left side.

(3) *Tetonius* or *Absarokius*, a fragment of the right mandible, containing the first and second molars.

The Lophiodont genus *Helaletes* has hitherto been recorded only from the Bridger, but it might reasonably be expected from the uppermost levels of the Lower Eocene since another Bridger perissodactyl, *Hyrachyus*, has recently been found in the upper horizon of the Wind River (Lost Cabin beds).

The Hyracothere tooth shows characters most closely approached by the smaller specimens of *Eohippus* from the upper Wind River, as well as by specimens from the upper Huerfano, which is now regarded as the probable equivalent of the almost barren Bridger A.

The tiny jaw fragment of the Tarsiid cannot definitely be assigned to either of the genera mentioned because it lacks the diagnostic front teeth.

Tetonius, the type species of which is *Anaptomorphus homunculus* Cope, is recorded from the Gray Bull and Lysite horizons of the Bighorn and Wind River basins respectively, while the closely related *Absarokius* is from the Lysite and Lost Cabin horizons of the Wind River. The jaw appears to be of a new species, somewhat more progressive than any described form of either genus.

These three specimens seem to represent a fauna intermediate between that of the upper Wind River and that of Bridger B. It may belong to the base of the Bridger (Hor. A), the mammalian fauna of which is practically unknown, correlation with the upper Huerfano being made on a single specimen of Titanothere. In any event the McCullock Peak horizon is close to the border line between the Lower and Middle Eocene.

Dr. W. D. Matthew, who has also examined these teeth, concurs in the above identifications and in the conclusions regarding the age of the beds in which they were found.

Blocks, bowlders, and smaller fragments of dense cream to buff limestone are found on the summit of Middle Peak, as well as on the ridge that extends south and in the ravines cut below it. In an area on the summit about 600 feet square, there are no less than twenty blocks more than 3 feet in maximum dimension, and the largest is 5×5×10 feet. Most of the blocks are rudely rectangular and appear to be bounded by bedding planes and joints, although the surfaces are pitted and grooved by the solvent action of water. The blocks are irregularly distributed and there can be no doubt that they are not in place. The size, shape, and composition of the blocks as well as their distribution, are similar to those described by Granger and Sinclair (9*a*), to which a glacial origin was ascribed. Fossils collected from one of the blocks have been examined by Dr. George H. Girty, who reports that the following species are present: *Cliothyridina, crassicardinalis, Eumetria Verneuliana, Schuchertella aff. Chemungenis, Spirifer centronatus, Triplophyllum* sp. Dr. Girty states that this is a characteristic Madison fauna (Mississippian).

This collection may be compared with the following collection, also identified by Dr. Girty as belonging in the Madison limestone. It was obtained about 50 feet above the southwest base of the block of limestone that forms Chalk Mountain, west of Cody, where it overlies beds of Cretaceous age: *Triplophyllum excavatum, Schuchertella aff. Chemungensis, Camarotoechia metallica* (?), *Spiriferina soliderostris*, *Cliothyridina crassicardinalis*, *Eumetria Verneuliana*, *Platyceras* sp.

South Peak lies about 8,000 feet southeast of Middle Peak and is formed by the conjunction of three smooth ridges that extend northwest, southwest, and east, respectively. The space between these two peaks is a smooth, rolling flat covered with sagebrush, and no rock outcrops were recognized in it. Just below the summit of this peak and well distributed around it there are six rugged outcrops of cream-colored limestone, each from 50 to 75 feet long. The limestone outcrops do not exhibit bedding but are highly shattered and several are entirely made up of angular fragments of limestone, one to ten inches in diameter, which are imbedded in a fine sand of similar material. The only fossils noted in these outcrops are a few crinoid stems, but the texture resembles that of the Madison limestone blocks on Middle Peak.

The best evidence of the character of the beds under the limestone is obtained at the head of a ravine on the northeast side of the peak, where the smooth surface near the summit merges with bad lands that show horizontal Wasatch material. No fossils were found at this locality. The evidence at South Peak indicates that a triangular cap of crushed Madison limestone, about 600 feet long and 400 feet across the base and about 80 feet thick, overlies horizontal Wasatch beds.

The summit of South Peak lies at the northwest end of an area about 3,000 feet in diameter within which there are eleven smaller and lower hills each of which shows outcrops of limestone breccia more than 50 feet long. Figure 4 shows one of the largest of these outcrops, in which the bedding is still preserved. It is 200 feet long, about 25 feet thick and, although it yielded no fossils, the texture indicates that it is probably part of the Bighorn limestone (Ordovician). Farther southeast these low hills merge with gravel-covered flat terraces that extend to the east and southeast toward the center of Bighorn Basin. Near the center of the hills, capped by limestone, there is a flat depression 500 feet in diameter at the northwest edge of which is Markham Spring, at an elevation of 5,850 feet. Even at the end of August, in the dry season of 1919, it yielded about two gallons a minute of clear non-alkaline water.

Another similar spring lies about 3,000 feet southwest at a lower elevation. These springs appear to be supplied from a thin mantle of mingled limestone breccia and sand from the Wasatch beds that becomes sufficiently saturated with water during the wet season to yield a small flow throughout the year. No other perennial springs are known within ten miles.

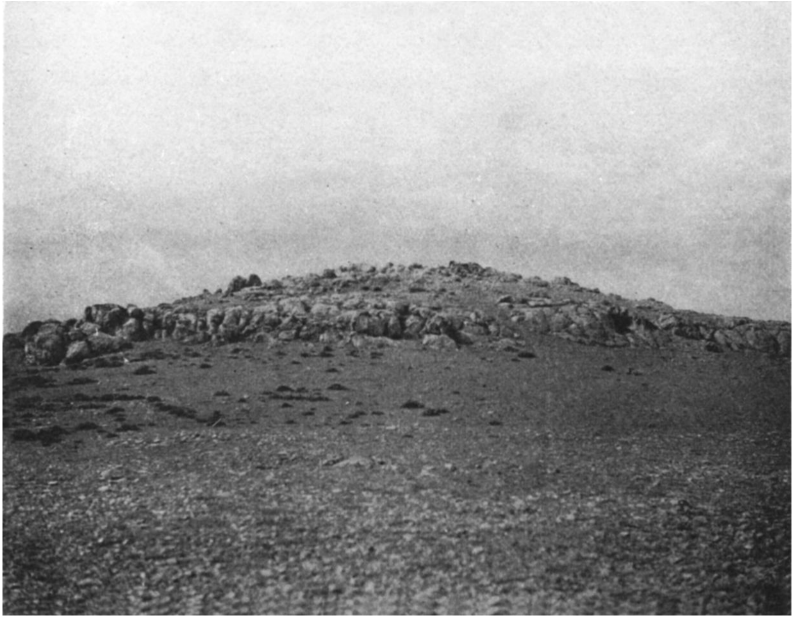


FIG. 4.—Bighorn limestone (?) overlying Wasatch (or Bridger?) beds on a hill near East Peak, McCullock Peak region, near Cody, Wyoming.

The significance of the McCullock Peak exposures may be briefly summarized. Before Dake's work was done in 1916, the McCullock Peak exposures might have been as puzzling as Heart Mountain to the geologists who examined that region some years ago (5, 6), and who considered that the block of Madison limestone which forms its summit was a plug bounded by a circular fault. In the light of Dake's work, there can be little doubt that the blocks of limestone in the vicinity of South Peak are parts of a layer of limestone that was thrust from the west, probably from the region near Sheep Mountain between the north and south forks of Shoshone River, 28 miles west. It is impossible to imagine that the McCullock Peaks blocks are somehow related to another overthrust or to some obscure and complex structure, for the structure of the beds between the peaks and Sheep Mountain is completely shown in the canyon of Shoshone River (14).

The recognition of mammalian fossils characteristic of the Bridger formation of western Wyoming under the blocks of Madison limestone shows conclusively that the period of overthrust was no older than these beds.

PHYSICAL FEATURES OF THE OVERTHRUST

Sufficient information is not yet available to make a comprehensive statement concerning those features of the overthrust that are needed to interpret the conditions under which it developed. It may be that the thick masses of "early basic breccias" cover so much of the mountainward portion that a satisfactory explanation can never be given. The known exposures permit the following summary of its features:

1. The lithology of the beds and few fossils collected in the mountainward area indicate that the base of the overthrust is uniformly the base of the Madison limestone. Dake states that the base of the Heart Mountain block is Madison limestone. On the other hand, although the few bowlders on Middle Peak yield Madison fossils, the lithologic features of the East Peak remnants resemble the Bighorn limestone. The base of the overthrust is, therefore, probably not the same horizon throughout. A limestone breccia is present at the base of all of the blocks that were examined. In the few days available in the mountain region, the writer was unable to confirm Dake's conclusion that there are two surfaces of overthrust. Although the presence of Sundance fossils under the Chalk Mountain Block appears to be evidence that such is ithe case, the exposures along South Fork, where a lower surface s also mapped, do not appear to demand this interpretation.

2. The elevation of the base of the remnants of the overthrust block decreases from about 7,200 feet on Carter Mountain to, about 6,800 feet on Sheep Mountain, then increases to about

9,500 feet on the divide between Rattlesnake and Dead Indian Creeks. The base of the Heart Mountain remnant stands at about 7,200 feet and the McCullock Peak remnants from 6,100 to 6,200 feet. Rattlesnake Mountain, a persistent ridge which attains an elevation of 9,100 feet and lies between these two groups of remnants, was examined but does not appear to retain any remnants of the overthrust block, although it once overlay the mountain. It cannot be stated assuredly yet whether the differences in elevation here indicated represent the form of the original surface of overthrust or whether the surface has been subsequently warped. Although parts of the region have been warped since the deposition of the bedded tuff near Owl Creek, tentatively correlated with the "early acid breccias" (lower Eocene), the writer believes that a large part of the noted differences represent the form of the surface over which the block was thrust.

3. The structure and attitude of the remnants of the overthrust block indicate that it was a relatively simple, unfolded layer of rock. The thickness can only be conjectured. The entire Paleozoic, Mesozoic, and Fort Union sections above the Deadwood shale (Cambrian) are about 17,000 feet thick. In attempting to estimate the probable thickness of the block, it must be borne in mind that it was largely removed by erosion before the outburst of "early basic breccias" (upper Miocene). The writer would tentatively estimate the thickness near the mountains at 15,000 feet, but the eastern edge was probably much thinner.

4. The surface upon which the overthrust moved is cut across a sharply folded belt of rocks that range from the pre-Cambrian granite to beds that appear to represent horizon A of the Bridger formation. No part of this surface that has been studied appears to be a fracture across the beds, but it is probably a surface of erosion. To this extent it resembles Willis' interpretation of the Lewis overthrust (17).

5. Dake mapped the overthrust in an area thirty miles long and the McCullock Peak exposures indicate a minimum thrust of twenty-eight miles. Only casual consideration of the regional geology is needed to convince one that the overthrust must have involved a much larger area, over which it can probably be traced.

6. The relations of the border Wasatch and the residuals east of Sunshine indicate that the border belt of folds had assumed their present form and were truncated by erosion before these beds were laid down. Apparently, therefore, the folds were developed considerably earlier than the overthrust.

AGE OF THE OVERTHRUST

As a result of his work Dake concluded that the overthrust was younger than certain beds along the north and south fork of Shoshone River, tentatively correlated with his Fort Union (?) formation. He also concluded that the overthrust was older than the "early basic breccias."

The short time available to the writer in this region in 1919 only permitted the following conclusions:

1. The beds exposed along the north fork of Shoshone River under the "early basic breccias" (13), and locally under remnants of the overthrust block resemble lithologically those 1,000 to 1,500 feet above the base of the Fort Union formation in the Bighorn Basin and lack the arkoses which are rather characteristic of the Bighorn Basin Wasatch. On the other hand they yield collections of leaves, among which F. H. Knowlton has recognized "Aralia notata Lesq." which though considered to be a Fort Union species, has not yet been recognized in the Bighorn Basin Fort Union, but is present in most of the collections from the "early acid breccias" in Yellowstone Park and the tuffs north of Owl Creek. The beds yield numerous bone fragments, largely turtle skutes, not yet recognized in the Bighorn Basin Fort Union, but common in the Bighorn Basin Wasatch. Although existing evidence is conflicting, the writer is inclined to consider that the beds are to be correlated with the border Wasatch.
2. The overthrust is older than the "early basic breccias" because the breccias locally lie in channels cut 200 to 300 feet below the overthrust surface.
3. The period of erosion that followed the overthrust and preceded the deposition of the "early basic breccias" was sufficiently long to destroy most of the beds that made up the thrust block, for the thickest remnant, that which makes up the summit of

Sheep Mountain, is only 1,000 feet thick and there are large areas over which the block is completely removed and "early basic breccias" rest on Wasatch beds (?).

TERTIARY DEFORMATION AND SEDIMENTATION IN THE BIGHORN BASIN

The table opposite p. 556 is presented at this time in the hope that it may aid in a better understanding of the relation of the Heart Mountain overthrust to the other deformations of the Bighorn Basin. It is not considered necessary to present in this paper any more of the evidence on which the conclusions are based.

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PRELIMINARY CORRELATION OF TERTIARY DEFORMATION AND SEDIMENTATION IN BIGH

GEOLOGIC AGE		ABSAROKA-OWL CREEK MOUNTAIN FRONT		BIGHORN BASIN		
				Border Belt		Central Part
		Deposition or Erosion	Deformation	Deposition or Erosion	Deformation	Deposition or Erosion
Miocene	Upper	Early basic breccias (widespread)		Basic tuff (?) (local)		(?)
	Lower	Erosion		Erosion (?)		Erosion (?)
Oligocene		Erosion		Erosion		Erosion (?)
Eocene	Upper	Erosion	Normal faults (local)	Erosion	Normal faults (local)	Erosion (?)
		—(Unconformity— (?))	—Heart— Mountain overthrust	—(Unconformity— (?))	—Heart— Mountain overthrust	—(?) —
	Middle	"Early acid breccia" (local)		Andesitic tuffs (local)		Andesitic tuffs (?) (local)
		—(Conformity) — Border Wasatch (local)		—(Conformity) — Border Wasatch (local)		—(?) —
	Lower	Erosion		Erosion		Bighorn Basin Wasatch { Tatman Mtn. beds Lost Cabin beds Lysite beds Gray Bull beds Sand Coulee beds } Subdivisions of Sinclair and Granger
		—(Unconformity)		—(Unconformity)		—(Unconformity (?)) —
Basal Eocene ("Paleocene")			Extensive normal faults Large folds Widespread uplift		Local normal faults Small folds Local uplift	
		Fort Union (?)	Sinking (?)	Fort Union	Widespread sinking	Clark Fork beds of Sinclair and Granger Fort Union
		(Local unconformity) —		(Local unconformity) —		—(?) —
Tertiary (?)[1]			Local warping		Local warping	
		Lance formation (?)	Sinking (?)	Lance formation	Sinking	Lance formation

[1] The Lance formation is here placed in the Tertiary (?) to conform with the usage of the U.S. Geological Survey, although the local evi
formability with the underlying cretaceous beds.

ARY CORRELATION OF TERTIARY DEFORMATION AND SEDIMENTATION IN BIGHORN BASIN

ABSAROKA-OWL CREEK MOUNTAIN FRONT		BIGHORN BASIN			
		Border Belt		Central Part	
Deposition or Erosion	Deformation	Deposition or Erosion	Deformation	Deposition or Erosion	Deformation
Early basic breccias (widespread)		Basic tuff (?) (local)		(?)	
Erosion		Erosion (?)		Erosion (?)	
Erosion		Erosion		Erosion (?)	
Erosion (Unconformity (?)) "Early acid breccia" (local)	Normal faults (local) Heart Mountain overthrust	Erosion (Unconformity (?)) Andesitic tuffs (local)	Normal faults (local) Heart Mountain overthrust	Erosion (?) (?) Andesitic tuffs (?) (local)	Heart Mountain overthrust
(Conformity) Border Wasatch (local) Erosion (Unconformity)		(Conformity) Border Wasatch (local) Erosion (Unconformity)		(?) Bighorn Basin Wasatch: Tatman Mtn. beds, Lost Cabin beds, Lysite beds, Gray Bull beds, Sand Coulee beds (Subdivisions of Sinclair and Granger) (Unconformity (?))	Local depression
	Extensive normal faults Large folds Widespread uplift		Local normal faults Small folds Local uplift		Depression
Fort Union (?) (Local unconformity)	Sinking (?)	Fort Union (Local unconformity)	Widespread sinking	Clark Fork beds of Sinclair and Granger Fort Union (?)	Widespread sinking
	Local warping		Local warping		(?)
Lance formation (?)	Sinking (?)	Lance formation	Sinking	Lance formation	Sinking

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mation is here placed in the Tertiary (?) to conform with the usage of the U.S. Geological Survey, although the local evidence indicates con-
underlying cretaceous beds.

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